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Original Paper

Research on the Application of Automated Storage/Retrieval System in the Warehouse Management of Automotive Rubber Product

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Abstract

Modern warehousing and logistics technology has promoted the widespread application of automated storage/retrieval system (AS/RS) in the automotive rubber products industry. In view of the problems of many types of automotive rubber products, mixed brands, and difficult batch management, the traditional forklift stacking and manual inventory models are inefficient, error-prone, and difficult to meet the needs of industrial development. This article combines the material characteristics of automotive rubber products to explain the functional positioning, design key points and implementation methods of the AS/RS. Based on the production capacity forecast and inventory analysis, the number of pallets and rack layout were determined, the main equipment parameters such as stackers, shuttles, and AGVs were clarified, and six functional areas were divided into receiving, sorting, caching, warehousing, shipping, and tool storage, realizing automated scheduling and information management of incoming and outgoing warehouses. This design solution can effectively improve space utilization and operating efficiency, achieve full traceability of materials, and provide a feasible reference for the intelligent upgrading of warehousing in the automotive rubber products industry.

Keywords

Warehousing and logistics technology, Warehouse management, AS/RS, Rubber product, Rack layout

1. Introduction

In the production and distribution links of the automotive rubber products industry, the warehousing and logistics system is the key support to ensure the efficient operation of the enterprise, control operating costs and improve customer service levels. Automotive rubber products, such as brake diaphragms, seals, hoses, etc., feature a wide variety of products, large batches, complex storage environment requirements, and high timeliness management requirements. Traditional warehousing methods often face problems such as low space utilization, low operating efficiency, and difficulty in ensuring inventory accuracy and traceability. As a high-density, information-based, and intelligent modern warehousing solution, AS/RS can significantly improve storage capacity and operating efficiency under limited land resources, and enhance the level of real-time management and control of materials and finished products. (Azadeh et al., 2019; Borovinšek et al., 2021) Therefore, studying the specific application of AS/RS in the warehousing of automotive rubber products has important practical significance and engineering application value for optimizing corporate warehousing and logistics systems, reducing operating costs, and improving order response speed and product delivery quality.

Regarding research issues related to warehousing logistics optimization, domestic and foreign scholars have adopted diversified methods and ideas from different perspectives. Silva et al. (2020) addressed the integration of storage location and order picking in warehouse planning by introducing and simulating four special cases with imposed routing policies (return, S-shape, midpoint and largest gap). Su et al. (2022) proposed two mathematical optimization formulations, using picking positions and picking aisles respectively as modeling units, to solve for the optimal solution of the multi-block layout problem in a novel cross-aisle warehouse layout. Luu et al. (2022) took the ATP entity warehouse as a case study, integrating the TSP traveling salesman algorithm with a classification-based storage allocation model, and utilized Lingo software to develop an optimized picking path scheme. They validated the model using real operational data from the warehouse. Ben Amor et al. (2026) focused on green and sustainable optimization of staff scheduling and human resource allocation by integrating the fuzzy analytic hierarchy process (FAHP) with a multi-objective optimization model, constructing a triple-bottom-line framework covering economic, environmental, and social dimensions, and empirically validating it using a hardware retail warehouse in Tunisia. Zhou et al. (2026) addressed the challenges posed by order fluctuations during major e-commerce promotions, the massive number of SKUs, and the dynamic and ever-changing nature of demand, by proposing a fractal deep learning model combined with a particle swarm optimization algorithm (FDLM-PSO), aiming to enhance the efficiency and adaptability of e-commerce warehousing and logistics. Roodbergen et al. (2008) established a quantitative model for multi-block parallel aisle layout optimization, with the objective of minimizing the total picking travel distance, to validate the model's applicability to various picking strategies, including S-type and return-type. Kalafat et al. (2010) considering warehouse replenishment as an implicitly high-cost operation, adopted approximate dynamic programming (ADP) for modeling, differentiating between peak and off-peak periods to construct a 0-1 integer programming model that integrates demand forecasting to guide daily replenishment decisions. Yang and Wen (2025) addressed the pain points of small and medium-sized e-commerce enterprises sharing warehousing spaces and storage areas, as well as the disorganized co-storage of multi-merchant SKUs, by developing a data-driven dynamic storage location optimization model based on reinforcement learning (RL). This model synchronizes real-time order and inbound/outbound data from multiple merchants, thereby overcoming the limitations of traditional storage location optimization, which relies on fixed historical data. Kala et al. (2025) developed a fuzzy dematel-electre multi-criteria evaluation framework to assist enterprises in achieving cost reduction and optimal selection in intelligent warehouse renovation. Hosseini et al. (2025) proposed an innovative approach integrating time series analysis with reinforcement learning to enhance demand forecasting accuracy and optimize warehouse operations, thereby improving inventory control by balancing product availability while minimizing holding and shortage costs. Based on the above research results, this paper specifically designed an automated three-dimensional warehousing and logistics system in order to improve and optimize the logistics system of the automotive rubber products industry, thereby promoting the improvement of the overall logistics service level of the industry.

2. Current State Analysis of Storage Management in the Automotive Rubber Products Industry

With the sustained development of my country's economy and the in-depth transformation of the industrial structure, the automotive rubber products industry is an important supporting industry for the automotive industry, and its warehouse management level is directly related to the overall operating efficiency of the industry. Currently, our country is in a critical period of socialist modernization, and the automotive rubber products industry is gradually transforming from the traditional mass production model to an intelligent and lean manufacturing model. In this transformation process, warehousing and logistics activities play an irreplaceable supporting role. However, the logistics, transportation and warehousing management of the automotive rubber products industry have long been the main bottleneck restricting the quality and efficiency improvement of the industry.

There are many types of raw materials for automotive rubber products, mainly including natural rubber, synthetic rubber, various reinforcing agents and vulcanization aids. Their procurement and distribution efficiency are highly dependent on external factors such as raw material market fluctuations, climate and environmental changes, and international trade conditions. For example, the origin characteristics of natural rubber make it susceptible to seasonal climate and origin policies, thereby increasing the uncertainty of logistics supply and warehousing adjustment pressure. When the external environment changes, the efficiency of logistics and distribution is significantly reduced and the transportation cycle is extended, which not only affects the continuity of production, but may also directly restrict the delivery of products in the downstream vehicle and after-sales markets, thereby affecting the economic benefits and market reputation of the enterprise. Looking at the industry as a whole, although modern logistics technology continues to innovate, and the gradual application of information technologies such as automatic identification, warehouse management systems, and transportation scheduling systems has improved the logistics transportation speed and efficiency of automotive rubber products to a certain extent and shortened the time in transit for finished products, the upgrade of the logistics system within the industry is still uneven. A large number of small and medium-sized enterprises still use traditional manual handling, flat stacking and simple rack storage methods. Problems such as low warehouse space utilization, inefficient inbound and outbound operations, and lagging inventory information updates are prominent. More importantly, automotive rubber products are characterized by easy aging, high weather resistance requirements, and sensitive storage cycles. It is difficult to achieve accurate "first in, first out" and expiration date control in traditional warehousing environments, resulting in increased quality risks and inventory losses.

Furthermore, automotive rubber products generally rely on manual inspection during the incoming and outgoing process. Operators check the product model, quantity and quality status one by one. This not only takes a long time, but also is prone to problems such as misissues, omissions or lags in information entry under large-volume, high-frequency operations. At the same time, warehousing inventory has a heavy workload and a long cycle, and some products have hidden quality changes such as aging and deformation. It is difficult for traditional accounting verification methods to detect abnormal conditions during the storage process in a timely manner. Inaccuracies in stored information and discrepancies between inventory data and actual conditions occur from time to time, which seriously restricts the improvement of enterprises' ability to respond to orders, inventory turnover and cost control.

Generally speaking, the current logistics and warehousing management methods of the automotive rubber products industry have been unable to adapt to the requirements of modern production and lean distribution. There is an urgent need to combine the actual situation and operating characteristics of the industry to introduce advanced warehousing and logistics systems such as AS/RSs. Through the integrated application of high-rise racks, automated access equipment and information management platforms, comprehensively improve warehousing space utilization, operating efficiency and data accuracy, and promote the transformation of the logistics management system of the entire industry in an intelligent and intensive direction.

3. Function Analysis of AS/RS in the Storage of Automotive Rubber Products

In the entire process of automotive rubber products from production to sales, the traditional logistics and warehousing model has many shortcomings. For example, after the products are processed, they need to be manually unloaded and loaded into trucks. After being transported to the warehouse, they are then manually unloaded and stacked. When they are sold out of the warehouse, they need to be loaded again. Repeated loading and unloading not only wastes human resources, but also seriously lengthens the operation cycle. In addition, the pallets and racks required for rubber products occupy a large space and require manual regular maintenance, further exacerbating the waste of resources and time. At the same time, due to the wide variety of products and complex batches, manual verification of inventory units, production dates, expiration dates, and customer order information results in a high error rate, a heavy inventory workload, and frequent mismatches in stored information. In order to effectively make up for the above shortcomings, the automotive rubber products industry urgently needs to combine its own actual conditions and introduce AS/RS and supporting logistics management systems to realize the intensification, informatization and intelligent transformation of warehousing operations.

This paper takes the AS/RS built by a large automotive rubber products company as the research object, and introduces an automated three-dimensional warehousing and logistics system that adapts to its production and warehousing characteristics. With the three-dimensional warehouse as the core, the system has 6 lanes, tens of thousands of cargo spaces, and is equipped with a variety of automation equipment such as stackers, shuttles, hoists, platforms, and conveyors. Since the number of automotive rubber products carried on each pallet is different, the system needs to take into account both operational stability and operating efficiency. To this end, a frequency conversion speed control strategy is adopted in the direction of movement to ensure smooth start and stop of the equipment and reliable operation; at the same time, the inbound area, outbound area and empty pallet return area are set up independently of each other to maximize the overall operating efficiency and space utilization of the warehouse.

3.1 Material Characteristic Analysis

Automotive rubber products mainly include natural rubber, synthetic rubber (such as styrene-butadiene rubber, butadiene rubber, nitrile rubber, ethylene propylene diene monomer rubber, etc.) and various vulcanized products. The product formulas of different types and brands are slightly different, but the main ingredients are rubber hydrocarbons, carbon black, vulcanizing agents, antioxidants, etc., and their basic physical and chemical properties are relatively consistent, as shown in Table 1.

Table 1. The Primary Components of Rubber Products

Primary component	Content range in the formula (parts /100 parts of rubber)	Mass proportion range (%)
Rubber hydrocarbon	100	45~70
Carbon black	20~90	15~40
Sulfurizing agent	0.5~6	＜3
Antioxidant	1~7	0.5~3

Raw rubber and unvulcanized rubber compound are flammable and can burn at high temperatures and release toxic smoke such as carbon monoxide and hydrogen sulfide, so they need to be kept away from fire sources. Some rubber may swell and degrade after contact with oil or strong oxidants; halogen-containing rubber (such as neoprene) may release corrosive hydrogen chloride gas when it decomposes at high temperatures. In addition, automotive rubber products should avoid direct sunlight, high temperature, high humidity and ozone environment during storage and transportation to prevent aging, cracking or adhesion. This type of product is not explosive, but is flammable. It can be managed according to Category 4.1 (Flammable Solids) or Category 9 (Miscellaneous Hazardous Substances). Fire prevention, ventilation, light protection and other measures need to be taken.

3.2 Storage Capacity Requirements Analysis

The company is a national high-tech enterprise, specialized in special new enterprises, focusing on the research and development, production and mold matching of automobile braking system parts. The core products can be divided into six categories with different packaging forms. The storage demand analysis based on the existing production capacity is shown in Table 2.

Table 2. Analysis of Storage Capacity Requirements for Various Products

Product name	Inventory volume	Number of pallets
Type A product	18t	129
Type B product	9t	68
Type C product	36t	112
Type D product	3t	10
Type E product	3t	20
Type E product	90t	248
Material bin	500	125
Total number of positions		712

3.3 Outbound/inbound Process Analysis

In the warehousing process of the automated three-dimensional warehouse for automotive rubber products, the pallet is first bound to the material information (product name, batch, expiration date, etc.) through QR code reading and writing or manual entry to achieve one pallet and one file. The system automatically allocates optimal storage locations based on material types, supports both automatic and manual modes, and is optimized based on first-in-first-out and partitioned storage principles. At the same time, storage location plans are formulated in advance to improve warehousing efficiency. After the warehousing is confirmed, the system updates the inventory ledger. When leaving the warehouse, the MES system receives instructions, and the system automatically compares the inventory batch numbers and selects materials according to the principles of first in, first out, nearest expiration date, and sampling first out. The outbound operation includes the outbound delivery of full pallets and empty pallet stacks. The system generates tasks and drives the equipment to transport materials to the outbound station. The entire process supports the entry, correction, cancellation and confirmation functions of outbound orders, and relevant documents can be printed to realize information management and traceability of the entire inbound and outbound process. In addition, the system should also cover basic data management, pallet barcode identification, inbound and outbound and defective product management, daily inventory, expiration date management, production/quality traceability, data query and report generation, system security protection, dispatch monitoring and equipment remote monitoring and other functions. The system operation process is shown in Figure 1.

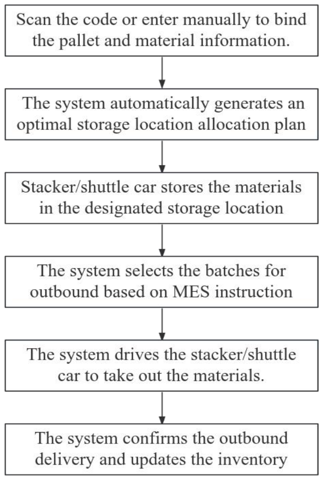

Figure 1. AS/RS Outbound/inbound Operation Process

4. Design and Implementation of AS/RS in the Warehousing of Automotive Rubber Products

The overall design of the AS/RS needs to be closely integrated with the characteristics of the production process to meet the six requirements of each process section for storage capacity, operating capacity and material transfer. Each functional area should be reasonably laid out and connected smoothly to give full play to system management capabilities. The system integrates advanced technologies such as computer control, network communication, data collection, infrared transmission, and fieldbus to achieve mechanization of sending and receiving operations, automation of warehouse logistics, digitization of warehouse management, three-dimensional storage units, and networked information transmission.

4.1 Main Functional Area Division

The AS/RS mainly includes five parts: pallet changing station, finished product packaging station, AGV transfer, three-dimensional warehouse and entry and exit station. Combining the actual operation process and material management needs, the system is divided into six functional areas: receiving area, sorting area, cache area, storage area, shipping area and work tool storage area. Each area is relatively independent and interlocked, and is equipped with safety guardrails, safety gratings, geomagnetic induction, sound and light alarms and interlocking parking and other safety measures. When people or vehicles enter any functional area, the equipment in the area will automatically alarm or interlock to stop to fully protect the safety of personnel, equipment and vehicles. The three-dimensional warehouse is equipped with two entrances and exits and supporting conveyor lines, which are used to connect the finished product production unit, pallet changing station, finished product packaging station and manual inspection area. AGVs (unmanned forklifts) are used to transport materials between various areas to realize automatic storage, withdrawal and transportation of materials and pallets. Among them, the receiving area is responsible for receiving and initial inspection of materials, the sorting area completes pallet binding and assembly, the cache area is used for transitional storage in and out of the warehouse, the warehousing area implements intensive storage and validity management, the shipping area performs outbound review and loading, and the operating tool storage area centrally manages various operating equipment and tools. The functional area division is shown in Figure 2.

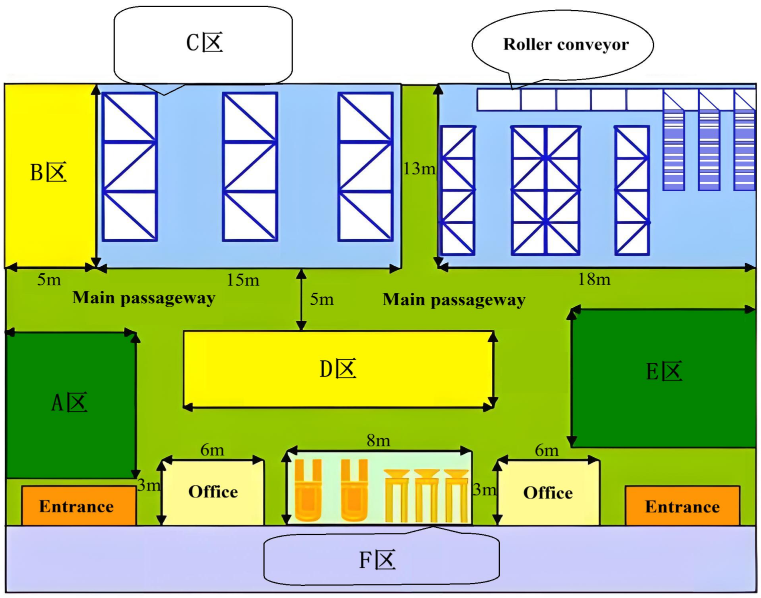

Figure 2. AS/RS Functional Area Division Plan Layout

Area A (Receiving Area): Mainly responsible for the arrival of materials, quantity counting, appearance inspection and verification of accompanying documents. Isolate and identify materials that do not meet storage requirements, and enter basic information to prepare for subsequent pallet binding and storage.

Area B (Sorting Area): Bind pallets and material information through QR codes or RFID technology to achieve "one pallet, one pallet". At the same time, he is responsible for the sorting, cleaning and maintenance of empty pallets, as well as material changing, merging, repackaging and other sorting operations to ensure that the specifications of the incoming materials are uniform and the information is complete.

Area C (Storage Area): High-rise racks and stackers are used to achieve intensive storage of products. Cargo spaces are automatically allocated based on material information, and meet special environmental requirements such as fire protection, light protection, ventilation, and anti-aging, and are equipped with temperature and humidity monitoring and fire protection linkage systems.

Zone D (Buffer Zone): It is set between the inbound and outbound operation line and the storage area, and is used to temporarily store materials that are about to be put into the warehouse or have just been shipped out. The cache area can buffer job peaks and balance system beats.

Area E (Shipping Area): Conduct a final review of the materials to be shipped according to the outbound instructions, print outbound documents and organize loading and delivery after confirmation. Supports the delivery of entire pallets and scattered picking out of warehouses, and is also responsible for empty pallet recycling, delivery record uploading and docking with the transportation system.

Area F (Tool Storage Area): It is specially used to store various working tools and auxiliary equipment required for the operation of AS/RS. This area should be reasonably planned and laid out to facilitate quick access and return for workers and improve operating efficiency.

4.2 Main Equipment Technical Parameters

The core hardware equipment of the system is mainly composed of roller conveyors, pallet sorters, gantry manipulators, AGV handling systems, etc. Its main technical parameters are detailed in Table 3.

Table 3. Main Equipment and Its Parameter Performance

Serial number	Main equipment	Function	Parameter
1	Roller conveyor	Adopting a roller conveyor structure, the pallet is equipped with a deceleration transfer mechanism	Rated carrying capacity:1500 kg Roller Specification: Φ76 Horizontal conveying speed: 16 m/min
2	Pallet sorter	The empty pallets can be automatically removed or stacked layer by layer	Stacking or palletizing capacity: 4 units/min Maximum stacking quantity per pallet: 9 units/group Cargo dimensions(L×W×H): 1500 mm×1 300 mm×170 mm
3	Gantry manipulator	The X-axis is driven in a dual-sided configuration; The Y-axis is driven by a servo motor coupled with a reducer, synchronous belt, and slider mechanism; The Z-axis is driven in the way of servo motor + reducer + hoisting + belt + movable pulley + synchronous belt	
4	AGV handling system	Responsible for the transportation of goods between various functional areas	Transfer method: forklift type; Cargo quality: 2 000 kg; Drive and steering mechanism:

			bidirectional, spin; Braking method: deceleration motor + electromagnetic brake
5	Shuttle car	Responsible for the handling of goods in the racks.	Rated load: 1 500 kg Empty speed: ⩾1.2 m/s Heavy load speed: ⩾0.8 m/s
6	Elevator	The goods can be lifted up and down, and the goods can be changed to different floors	Rated load: 1 500 kg Transmission system: sprocket type
7	Packaging machine	The goods are wrapped in film externally to prevent the stack from collapsing	Packaging efficiency: 3 min Stack Transfer Speed: 15 r/min(max)

4.3 Communication Network Structure System

The AS/RS for automotive rubber products has a large overall scale and complex equipment layout. It is necessary to design a reasonable communication network structure system based on equipment characteristics and operational requirements. The specific implementation is as follows:

(1) For high-speed mobile equipment such as stackers and shuttles placed centrally in three-dimensional warehouses, corresponding wireless base stations need to be deployed on the top of the racks to achieve full signal coverage within the warehouse to meet the real-time communication needs of mobile devices under high-speed operation. The use of wireless communication network mode not only effectively saves wiring costs and space, but also reduces the difficulty of construction and maintenance.

(2) In view of the characteristics of the automated three-dimensional warehouse of automotive rubber products with large space span and wide distribution of conveying systems, a distributed network architecture is usually selected. Set up remote substations in the equipment concentration area, use the PLC gateway inside the substation as an auxiliary node, use industrial Ethernet to collect the equipment status and operation information of each substation, and uniformly transmit it to the main station. The entire communication process is centralized controlled and scheduled by the master station CPU to ensure data real-time, reliability and system operation stability.

Through the above-mentioned combination of wireless communication and distributed networks, the automated three-dimensional warehouse for automotive rubber products can achieve efficient collaboration between mobile devices and fixed control systems, providing reliable communication support for the automation, informatization and intelligence of warehousing operations.

5. Conclusion

In the context of the deep integration of the Internet and manufacturing, the automotive rubber products industry urgently needs to systematically innovate the traditional warehousing and logistics model in order to enhance its core competitiveness and achieve the unity of economic and social benefits. As a key link connecting raw material procurement, production scheduling and product sales, the operational efficiency of the logistics system directly determines the company's operating costs and market response capabilities. Based on the product characteristics and management pain points of automotive rubber products, this article designs an automated three-dimensional warehousing and logistics system that adapts to industry needs. By rationally dividing the six functional areas of the receiving area, sorting area, cache area, warehousing area, shipping area and work tool storage area, and integrating advanced technologies such as wireless communication, distributed control, industrial Ethernet and AGV transfer, the system can effectively solve the outstanding problems in traditional warehousing such as low space utilization, low operating efficiency, difficult validity period management and lagging information traceability. At the same time, the system has realized the mechanization of sending and receiving operations, digitization of warehouse management, and networked information transmission, fully meeting the special requirements of automotive rubber products in terms of batch management, first-in-first-out, near-expiry date priority, and safe storage. To sum up, the AS/RS can not only meet the warehousing and logistics needs of the automotive rubber products industry to the greatest extent, but also bring significant economic and social benefits to enterprises by reducing operating costs, improving customer satisfaction, and enhancing market competitiveness. It has important engineering application and promotion value.

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